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An Automated Immittance Measuring System for Electroacoustic Transducers

Clementina M. Ruggiero and Theodore A. Henriquez

Underwater Sound Reference Detachment
P.O. Box 8337
Orlando, Florida 32856

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A fully automated method of obtaining immittance loops of piezoelectric transducers has been designed to be utilized in conjunction with the Hewlett-Packard 4192A Impedance Analyzer. The algorithm determines the frequencies at maximum and minimum immittances, the series and parallel resonance frequencies, and the resonance and antiresonance frequencies as well as the mechanical quality factor of the element under test. The collected data are plotted in the form of either admittance or impedance loops with evenly spaced points. The program has been implemented successfully as a means to rapidly obtain the admittance information of various loaded and unloaded transducers and transducer elements.

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CONTENTS

AN AUTOMATED MEASURING SYSTEM FOR ELECTROACOUSTIC TRANSDUCERS

INTRODUCTION

The precise measurement of immittance is a valuable tool for the analysis of electroacoustic transducers and piezoelectric materials. Immittance is used in the determination of transducer efficiency, electrical matching, and the tuning and analysis of transducer performance and of material parameters of active transducer materials. Previous techniques for immittance measurements involved the use of such devices as impedance bridges, analog voltmeters, phase meters, and some special analog devices like the vector impedance meter. All of the before mentioned devices suffer from one or more restrictions; e.g., speed, precision, or stability.

The HP Model 4192A Digital Network Analyzer is computer controlled and has the ability to make immittance measurements at high speed with excellent precision and stability. Combined with the developed circular approximation algorithm, the measurements can be made with greater efficiency to provide the maximum amount of information with the minimum number of data points. This method also allows for fast, accurate computation of critical points of immittance without knowing the series (parallel) resonance of the transducer. The optimization of data points is achieved by the determination of frequencies that will be quasi-uniformly distributed around the immittance circle as opposed to the "clustering" of frequencies above and below the frequency of maximum immittance.

Figure 1 compares an immittance circle defined by a linear sequence of frequencies with one in which the frequencies are generated from the circular approximation method. There are two hundred points in the linear frequency sweep of Fig. 1a and only fifty points in Fig. 1b. This circular approximation method has been implemented on various piezoelectric transducers and works exceptionally well in most cases. The timesaving is greatest when measuring high-Q transducers. Linear-spaced frequency points appear diluted on the steep slopes of the imaginary part of a high-Q immittance, as shown in Fig. 2. For low-Q curves the frequency distribution is more evenly spaced. When the data are presented in the form of imaginary verses real immittance, the data from high-Q systems are

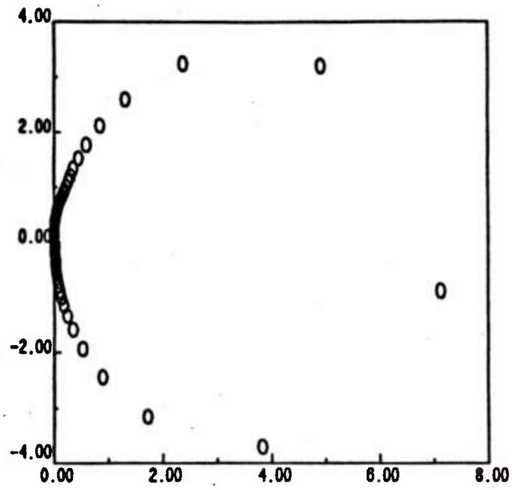

Fig. 1a – Immittance loop showing the distribution of data points resulting from a linear sweep of two hundred frequency steps.

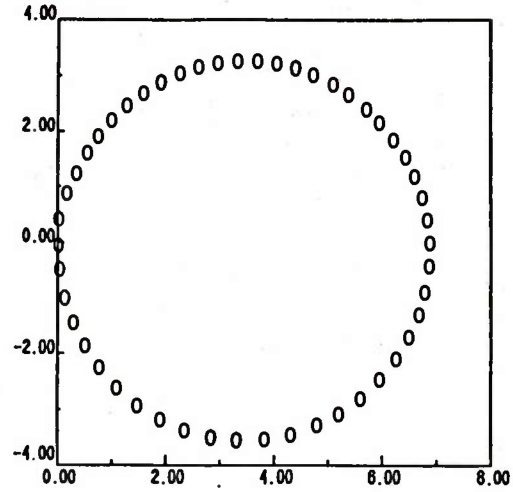

Fig. 1b – Immittance loop showing the more uniform distribution of only 50 data points when frequencies are determined by the circular approximation method.

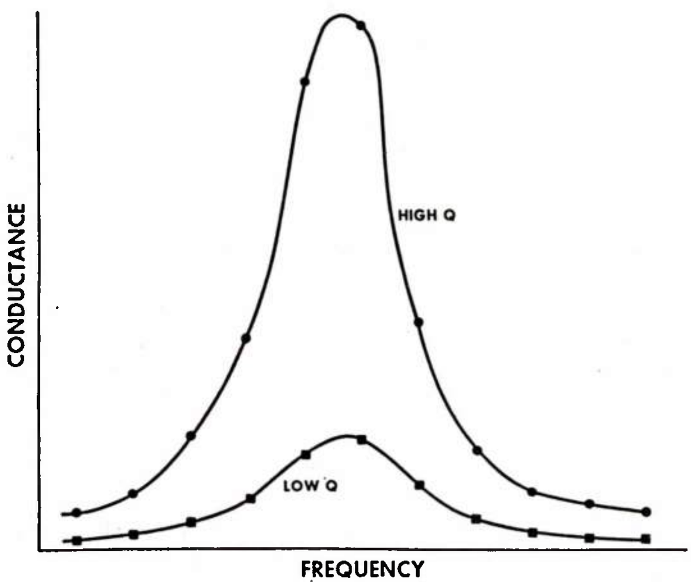

Fig. 2 – Distribution of data points for equally spaced frequencies on the imaginary part of the immittance curve for a high-Q system and for a low-Q system.

concentrated near the beginning and end of the immittance circle. For low-Q systems the data points approach a uniform distribution.

CIRCULAR APPROXIMATION ALGORITHM

The circular approximation method can be applied to admittance and impedance loops. Because of the similarity of application to impedance and admittance, and to avoid writing "impedance or admittance", the two quantities are implied when the term immittance is used in the following text. The differences between the admittance terms and the impedance terms will be discussed in the PROGRAM section of this report. Thoughout this report the word "points" appears many times with various meanings. To assure clarity three symbols are defined:

- The term "points(f)" refers to a frequency.
- The term "points(c)" refers to the ordered pair on the the theoretical circle.
- The term "points(i)" refers to the real and imaginary position on the immittance loop.

The method presented here will be based on the following equation:

$$\tan(\Theta) = \frac{L\left[\omega^2 - \omega_i^{\,2}\right]}{\omega R}. \qquad [1]$$

This equation is derived [1] from a simple equivalent circuit of a piezoelectric resonator, where L is the inductance, ω is the angular frequency, ω_i is a resonant frequency (series resonance when measuring admittance, parallel resonance when measuring impedance), Θ is the phase angle, and R is the resistance. Cady uses ω_0 (angular frequency of zero crossing) in Eq. (1) instead of ω_i. But ω_i is also an angular frequency at a zero crossing since a transformation of axes is performed with the circular approximation method. It is algebraically convenient to write Eq. (1) in the following form: Given ω, R, and Θ for three points(f), ω_i

and L are determined by applying Cramer's rule [2] to this expression:

$$\omega_i^2 + \frac{1}{L}\,\omega R\tan(\Theta) = \omega^2. \qquad [2]$$

By using the following equation

$$L\omega^2 - L\omega_i^2 - \omega R\tan(\Theta) = 0, \qquad [3]$$

the angular frequencies (ω) are determined as a function of the angle Θ by solving the quadratic equation. Equations (2) and (3) are the key equations used in the circle approximation method and will be referred to many times in the text of this paper. The argument used for applying Eqs. (1) through (3) to both impedance and admittance is found in Appendix A.

The algorithm used in determining the admittance or impedance loops consists of two major parts. First, the "best fit" circle that approximates the immittance loop is determined from parameters of the simple equivalent circuit of a piezoelectric resonator. Secondly, the circular approximation is then divided into equal arcs that are used to determine quasi-equally spaced points(i) on the immittance loop.

To determine the "best-fit" circle, one must first identify any three frequency points(f) on the immittance loop with the abscissa and ordinate identified as conductance and susceptance (or resistance and reactance), respectively. If previous knowledge exists about the transducer to be measured, these three points(f) are easy to identify. If however, there is no previous knowledge about the transducer, the program will assist the user in determining the three points(f).

The HP 4192 Impedance Analyzer measures the real and imaginary parts of immittance at each of these frequency points(f) and the ordered pairs of data are stored as (x_i, y_i), where i goes from 1 to 3 corresponding to each of the three frequency points(f). These ordered pairs are used in the general form of the equation of a circle:

$$x_iD + y_iE + F = -\left[x_i^2 + y_i^2\right] \quad [4]$$

$$\text{of center } \left[\frac{-D}{2}, \frac{-E}{2}\right] \text{ and radius } \frac{1}{2}\left[D^2 + E^2 - 4F\right]^{1/2}. \quad [5]$$

To find D, E, and F, we impose the condition that the coordinates of each of the given points(i&c) satisfy Eq. (4). When these values for D, E, and F are substituted in Eq. (5), we have the radius and center of the circle through the given points(i&c). By using the calculated radius and center, two points(c) located 120 degrees from a fixed initial point(i&c) are found as shown by the boxes in Fig. 1. The authors have arbitrarily chosen the fixed point(c) to be the second initial point(i). One may use any initial point(i) as long as it remains consistent throughout the entire procedure.

In order that this procedure apply both to loaded and unloaded transducers, a translation of axes is performed on all points(i) used in Eqs. (2) and (3). The formulas for the translation of axes are:

$$x_t = x_o - x_c + r \qquad \text{and} \qquad y_t = y_o - y_c \quad [6]$$

where $(x_c + r, y_c)$ is the new origin. The ordered pair (x_c, y_c) is the center of the circle, r is the radius, (x_o, y_o) are the old coordinates, and (x_t, y_t) are the old coordinates with the new origin. The slope [$\tan(\Theta)$] is determined by first applying Eqs. (6) to a given point(i). The resistance R, also found in the Eqs. (2) and (3), is replaced by the diameter or reciprocal of the diameter of the circle depending on which immittance loop is chosen. The quantities ω_i and L are calculated using Eq. (2) and the data of two intial points(i) along with information from the circle. With the calculated parameters (ω_i, L, and Θ) of the two 120-degree points(c), the frequencies ($\omega/2\pi$) at the 120-degree points(c) are calculated by applying Eq. (3). The HP 4192 Impedance Analyzer measures the conductance and susceptance (or resistance and reactance) at each frequency, and the points(i) are stored. These points(i) are illustrated by the "triangles" in Fig. 3.

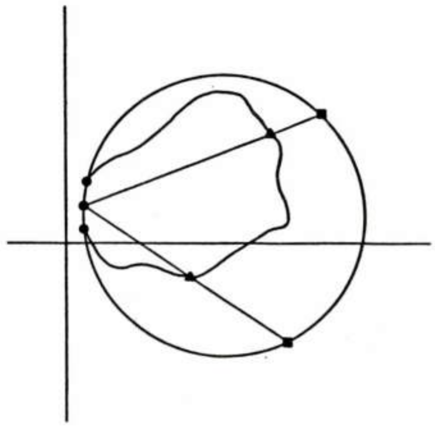

Fig. 3 - An immittance loop with a first-circle approximation.
Dots indicate the first three frequencies chosen.
Squares mark the 120° points.
Triangles represent associated points on immittance loop.

Now a new circle is calculated using the two 120-degree points(c) (triangles in Fig. 3) and the second intial point(i&c). Note that this new circle will be a better approximation to the immittance loop than was the previous one. This procedure iterates until two successive circles are within the desired tolerance. The result of this convergence is a "best-fit" circle, which is then divided into equal sectors, as shown in Fig. 4; the frequencies are found at each "triangle" location by applying Eq. (3).

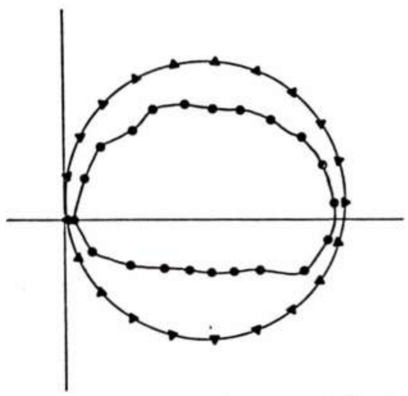

Fig. 4 - An immittance loop with a first-circle approximation.
Equally spaced points on the circle create quasi-equally spaced points on the immittance loop.

The HP 4192 Impedance Analyzer measures the conductance and susceptance at the "triangle" frequencies, and the immittance values are stored in a file. Note the dots on the immittance loop in Fig. 4 are not exactly "equally spaced", but certainly there is a better distribution of points(i)

than is obtained from a linear frequency sweep. This is what we previously referred to as quasi-equally spaced points(i).

CRITICAL FREQUENCIES

Once the loop is characterized with the desired number of quasi-equally spaced points(i), specific frequency points(f) are needed for later calculations of various transducer parameters. The frequency points(f) [3] that are of interest are:

f_m: frequency at maximum admittance (minimum impedance)

f_n: frequency at maximum impedance (minimum admittance)

f_s: frequency at maximum conductance

f_p: frequency at maximum resistance

f_r: resonance frequency (susceptance is zero)

f_a: antiresonance frequency (susceptance is zero)

f_{h_a}: frequency at maximum susceptance

f_{l_a}: frequency at minimum susceptance

f_{h_i}: frequency at maximum reactance

f_{l_i}: frequency at minimum reactance

When characterizing an admittance loop, the frequency points(f) f_m, f_s, f_r, f_p, f_{h_a}, and f_{l_a} are determined by a maze technique that will be described in the program section of this report. When an impedance loop is characterized, the frequency points(f) f_a, f_p, f_n, f_s, f_h, and f_l are determined. One may note that the frequency sets differ when calculating

impedance or admittance loops. The authors believe that the two most important points(f) are the series and parallel resonance (f_s and f_p). These points(f) can easily be found, and they occur for both loaded and unloaded transducers. Both of these conditions do not apply to the frequency pairs f_m, f_n and f_a, f_r. To determine the frequencies f_m, f_n one must do a frequency sweep, which can be rather time consuming. The points(f) f_a, f_r are easy to find by implementing root-finding techniques; however these points(f) do not always occur in loaded transducers. For these reasons, the focus has been on obtaining f_s, f_p. The reader may note that f_s is the frequency at maximum conductance; however, it is not the frequency of minimum resistance as can be seen in Fig. 5.

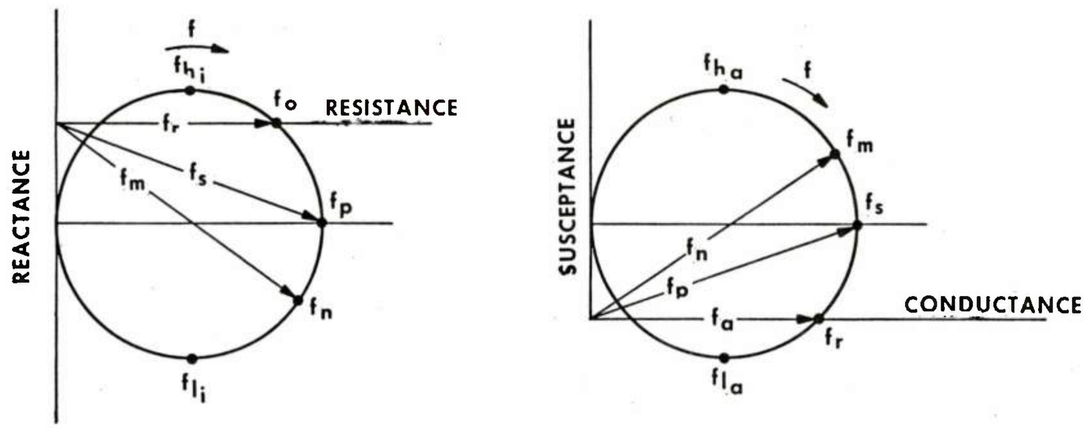

Fig. 5 - Impedance loop (5a) and admittance loop (5b), showing their critical frequencies.

Analogously, f_p is the frequency at maximum resistance; but it is not the frequency of minimum conductance.

The points(f) of secondary importance are the frequencies of minimum and maximum susceptance (f_{h_a} and f_{l_a}). These points(f), sometimes called half-power points(f), are used to compute the electrical quality factor Q. We also compute the frequencies of minimum and maximum reactance (f_{h_r} and f_{l_r}). These points(f), however, are not the half-power points(f) and cannot be used for calculating the quality factor Q. The only purpose for determining these points(f) is that they locate the frequencies at the top and bottom of the loop. The remaining frequencies are easily determined for the particular immittance loop calculated, and they serve as helpful

parameters for detecting problems.

PROGRAM

The computer program MICAM, presented herein, is by no means the best implementation of the circular approximation method. However, the authors feel confident that this program can be refined in a manner that would be applicable in any research or manufacturing environment. The MICAM program, written in FORTRAN 77, is run on a Digital Equipment Corporation VAX 11/780 computer at the Underwater Sound Reference Detachment of the Naval Research Laboratory as a research tool as well as a quality-control problem detector. A version of this program is also written in HP Basic and can be executed on the HP 9836. The MICAM program has been tested on various transducers, both in air and in water, and seems to perform exceptionally well. It does have limitations, which will be explained in detail in the RESTRICTIONS section of this report. Since the program is quite involved, the line-by-line descriptions of MICAM and the program listings are included in Appendix B. The purpose of examining individual program lines is to:

- Show how the algorithm has been implemented.
- Give differences in admittance and impedance loops.
- Explain how critical frequencies are determined.

The program MICAM calls three subroutines; SIMEQ, RSORT, and FILE. The SIMEQ subroutine solves simultaneous equations. The RSORT subroutine sorts numbers in descending or ascending order. And the FILE subroutine stores the immittance information in FORTRAN files.

RESTRICTIONS

Limitations exist in all algorithms and should be used as one criteria for choosing one method over another. The following paragraphs identify two examples where a linear frequency sweep would be preferable to

determining frequencies by the circular approximation method.

One problem occurs when running very low-Q or highly damped transducers where no loops are formed. Since the circular approximation method is designed to emulate the immittance loop with a circle, the algorithm fails to converge on very low-Q or highly damped transducers. The MICAM program accommodates this problem by allowing the user to perform a frequency sweep. If the transducer is of low Q, a linear frequency sweep will give quasi-equally spaced points(i), as illustrated in Fig. 2.

A second problem occurs when two or more resonances are in the same frequency region. They may appear as small or large satellite loops. Usually the small satellite loops are not a problem and MICAM will converge to the larger loop. Nevertheless, when immittance is the combination of loops of relatively the same size, MICAM converges to one of them, depending on the initial frequency given. This loop may not necessarily be the one desired. However, the authors feel that MICAM may be optimized for specific applications by relatively minor programming changes.

CONCLUSION

The circular approximation algorithm, when used with the HP 4192A Impedance Analyzer, makes a highly efficient system for measuring impedance and admittance of resonant electromechanical devices. The system has proven to be applicable to the measurement of active electromechanical materials as well as composite transducers. The algorithm has been used with excellent results on a VAX computer as well as on personal computers.

Although specifically developed as a research tool, the automated immittance measuring system is extremely well suited for quality-control and production testing of electromechanical transducers and materials.

ACKNOWLEDGMENTS

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REFERENCES

1. Walter Cady, **Piezoelectricity**, (Dover Publications, Inc., New York, 1964) pp. 336-340

2. Howard Anton, **Elementary Linear Algebra**, (John Wiley & Sons, Inc., New York, 1973) pp. 80-82.

3. "IEEE Standand on Piezoelectricity," IEEE Std. 176-1978 (The Institute of Electrical and Electronic Engineers, Inc., New York, 1978).

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APPENDIX A

Analysis for Applying Equations to Both Immittance Loops

The characteristic electrical property of a piezoelectric resonator is the equivalent series chain RLC in Fig. A1. The graphical representation of the RLC branch is more easily represented by the admittance which is represented as a circle referred to as the fiducial circle [1]. The graph can be easily extended to more complicated networks connected in parallel, such as C_o.

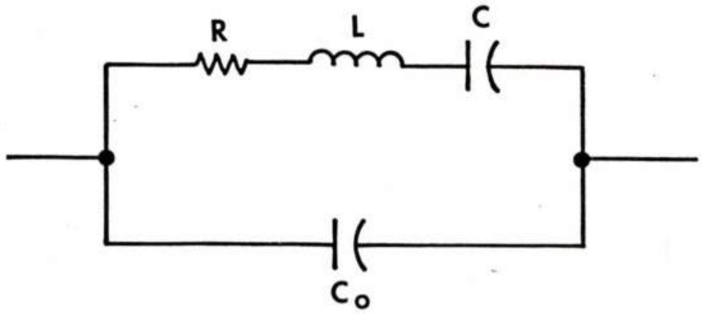

Fig. A1 - Simple equivalent circuit of a piezoelectric resonator.

The simple form of admittance of the RLC chain is all that is necessary to approximate the fiducial circle. The argument extends to the impedance representation in that all the information for the impedance circle is contained in the admittance circle. If

$$Y(\omega) = G(\omega) - jB(\omega),$$

then

$$\tan(\Theta) = \frac{-B(\omega)}{G(\omega)}. \qquad [A1]$$

Since $Z(\omega)$ is the complex reciprocal of $Y(\omega)$, $Z(\omega)$ can be written as

$$Z(\omega) = \frac{G(\omega)}{G^2(\omega) + B^2(\omega)} + j\frac{B(\omega)}{G^2(\omega) + B^2(\omega)}, \qquad [A2]$$

or $Z(\omega)$ can be written as

$$Z(\omega) = R(\omega) + jX(\omega). \qquad [A3]$$

Equating the real and imaginary parts of Eqs. (A2) and (A3) results in the following expressions:

$$R(\omega) = \frac{G(\omega)}{G^2(\omega) + B^2(\omega)}, \qquad [A4]$$

and

$$X(\omega) = \frac{B(\omega)}{G^2(\omega) + B^2(\omega)}. \qquad [A5]$$

For an impedance loop, $\tan(\Theta)$ can be written as

$$\tan(\Theta) = \frac{X(\omega)}{R(\omega)}, \qquad [A6]$$

or can be equivalently expressed by using Eqs. (A4) and (A5) as

$$\tan(\Theta) = \frac{-B(\omega)}{G(\omega)}.$$

Note that Eqs. (A1) and (A6) are identical except for being opposite in sign. Therefore for any ω in the admittance circle there is a corresponding ω of the same value in the impedance circle with the same but negative phase value.

APPENDIX B

Program Description and Listing

DESCRIPTION

This appendix contains a detailed description of MICAM as well as program listing. The program description supplements the CIRCULAR APPROXIMATION ALGORITHM section of this report and is necessary for a full understanding of this method. Program lines 1-76 are array declarations while lines 94-145 contain the interactive input section. There are several items of interest in this section. A question regarding speed is asked at line 98. Low speed provides an average measurement mode (approximately one measurement per second) to obtain measurement data of higher resolution and repeatability then at medium speed (5 measurements per second) or high speed (10 measurements per second). At line 112, the number of points(i) refers to the number of quasi-equally spaced points(i) that are desired on the immittance loop. In lines 118 and 120, the parallel or series resonance is required depending upon which loop is calculated. These frequencies are estimated from a priori knowledge. The more confident one is of these points(f), the smaller the frequency step size can be taken (line 125).

Lines 138-163 is a section of code that allows the user to perform a frequency sweep. This is executed only if, for some reason, the circular approximation method does not apply. The portion of code that includes lines 176-215 is the location where the conductance and susceptance (resistance and reactance) for the three initial points(f) are determined. The ARRAY variable contains the coefficents of Eq. 4. In line 216, the subroutine SIMEQ solves the three simultaneous equations, which ultimately results in the center and radius of the circle given in lines 218-220.

The code from lines 221-237 is used to solve Eq. (2) for ω_i and 1/L, which are used to calculate the frequencies at two initial points(i) and the motional inductance value L (lines 241-250). Line 252 is a decision statement that determines if the difference between two successive series

(parallel) resonant frequencies is within a desired tolerance. If the frequency is within tolerance, the program has determined the best fit ω_i and L for Eq. (1). If the tolerance is not met, a new and hopefully better-fit circle will be computed using the frequencies at the two 120-degree points(c) (lines 261-283). These 120-degree frequency points(f) are found by solving Eq. (3) and substituting the recently computed values for ω_i and L. This entire procedure repeats until the tolerance condition is met in line 252.

The second major computational portion of the MICAM program is found in lines 294-321. This portion uses the ω_i and L that meet the tolerance specifications and Eq. (3) to calculate the quasi-equally spaced points(i). The remaining portion of the program determines the critical frequencies described earlier in this report. The RSORT subroutine sorts the data from the largest to the smallest value. In line 322, the conductance (resistance) is sorted so that the first value in the array will be the f_s (f_p). The RSORT subroutine is called again in line 327 where frequency is the variable sorted. The remaining critical frequencies are determined by exercizing a maze technique. This technique is found in lines 337-384 and is based on previous knowledge on all immittance loops, shown in Fig. 5. The criteria used are:

$$f_m \leq f_s \leq f_r \leq f_a \leq f_p \leq f_n . \qquad \text{[B1]}$$

A critical frequency point(f) is searched only in the region wherein it could occur; i.e, it satisfies the inequalities of Eq. (B1). All of the critical frequencies are chosen from the points(i&f) of the immittance loop except for $f_p(f_s)$. The points(f) $f_p(f_s)$ require that more points(f) be calculated in order to have relatively accurate data. For example, when an admittance loop has been run, f_p is determined by switching the HP analyzer to the impedance mode, spotting the point(f) f_{1_a}, and sweeping the frequency until the frequency at maximum impedance is found. On the other hand, when an impedance loop has been run, fs is determined by switching the analyzer to the admittance mode, spotting the point(f) f_{h_i}, and then sweeping the frequency in reverse until the frequency of maximum admittance is found. This technique is illustrated in lines 408-431.

The remaining portion of the program can be considered a formatted output section that prints a table of all critical frequencies described and files the data points(i) for plotting. The plots that can be created include a graph of magnitude of immittance verses frequency and a graph of the imaginary part of immittance verses the real part of immittance. Also the critical frequencies are stored so they may be overlayed on the immittance plot as shown in Figs. B1 and B2, which are examples of admittance loops obtained on a USRD Type F42A transducer in air and in the USRD Lake Facility by MICAM.

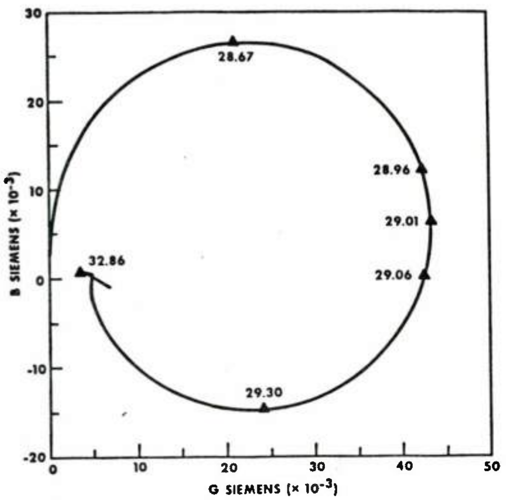

Fig. B1 - Admittance loop obtained on an F42A transducer in air.

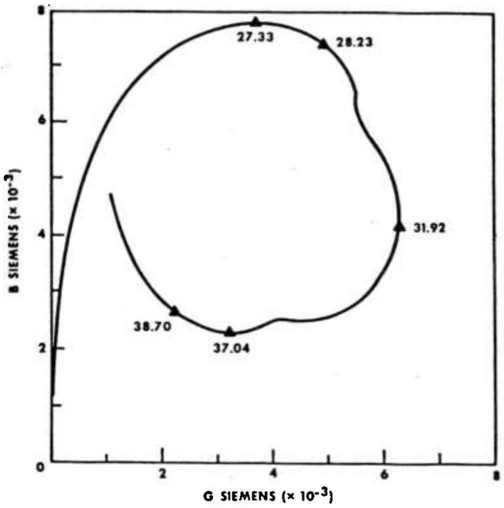

Fig. B2 - Admittance loop obtained on an F42A transducer in the USRD Lake Facility.

There are several differences in MICAM for impedance or admittance loops. The first difference, of course, is that the HP analyzer is in the proper mode for the desired measurements (lines 171 and 172). Secondly, there is a difference in the motional resistance (R) found in Eqs.(1) through (3) for the two loops. In the admittance mode, R is approximated by the reciprocal of the diameter, and in the impedance mode, R is approximated by simply using the diameter of the circle. Two interactive runs of the program MICAM are included in Appendix B, which illustrate how

the user can obtain results in either immittance mode.

LISTING

```
C       MICAM PROGRAM

C       WRITTEN BY TINA RUGGIERO
C       FEBRUARY, 1983

C THIS PROGRAM DETERMINES A FREQUENCY SWEEPING FUNCTION BY APPROXIMATING
C       AN ADMITTANCE LOOP WITH A PERFECT CIRCLE.   ALSO FN,FM,
C       FA,FR, AND ADMITTANCE LOOPS ARE STORED AND ARE AVAILABLE
C       FOR PLOTTING.


        DOUBLE PRECISION DEF(3),CONS(3),ARRAY(3,3),COEFF(3,3),COLUMN(3),ANS(3)
        REAL RES(1000), XES(1000), FREQ(1000),X(6),Y(6),F(6),FR(3),FRE(1000)
        REAL K33,CE,CP,COB,CAP,XCOF(5),COF(5),ROOTR(5),ROOTI(5),ADM(1000)
        REAL CRX(8),CRY(9),MAG(1000)
        COMMON FR,AMR,RR,XR,FA,AMA,RA,XA,FM,AMM,RM,XM,FN,AMN,RN,XN,XH,XL
        COMMON RH,RL,FH,FL
        COMMON /LENGTH/LEN


        BYTE ANSWER(80)

        BYTE A(13)                                          I VOLTS
        DATA A /'O','L',0,0,0,0,0,0,0,0,0,'E','N'/

        BYTE B(12)                                          ! START
        DATA B /'T','F',0,0,0,0,0,0,0,0,'E','N'/

        BYTE C(13)                                          I STOP
        DATA C /'P','F',0,0,0,0,0,0,0,0,0,'E','N'/

        BYTE D(12)                                          I STEP
        DATA D /'S','F',0,0,0,0,0,0,0,0,'E','N'/

        BYTE E(13)                                          I SPOT
        DATA E /'F','R',0,0,0,0,0,0,0,0,0,'E','N'/
        BYTE IDSP(4)
        DATA IDSP /'F','1','A','4'/                IDISPLAY CAP
                                                          DIS
        BYTE IADV(2)                                        !STEP UP
        DATA IADV /'W','2'/

        BYTE IREV(2)                                        ISTEP DOWN
        DATA IREV /'W','4'/

        BYTE IAD1(2)
        DATA IAD1 /'D','1'/                           IDATA READY ON

        BYTE IAD0(2)
```

```
          DATA IADO /'D','0'/                    !DATA READY OFF

          BYTE IADM(4)
          DATA IADM/'F','1','A','2'/             !DISPLAY G B

          BYTE IAV1(2)                           !AVERAGE ON
          DATA IAV1/'V','1'/

          BYTE IAH1(2)                           !HIGH SPEED ON
          DATA IAH1/'H','1'/

          BYTE IAH0(2)                           !HIGH SPEED OFF
          DATA IAH0/'H','0'/

          BYTE IAMM(2)                           !MANUAL SWEEP
          DATA IAMM/'W','0'/

          BYTE IAC3(2)               !PARALLEL CIRCUIT (ADMITTANCE)
          DATA IAC3/'C','3'/

          BYTE IAC2(2)                 !SERIES CIRCUIT (IMPEDANCE)
          DATA IAC2/'C','2'/

          BYTE IAEX(2)                           !TRIGGER THE READING
          DATA IAEX/'E','X'/

          IADDR=1
          ITIMO=30
          LUN=1
          CALL BTAKEC(LUN,ISTAT)                 !TAKE CHARGE OF GPIB
          CALL BDEVCL(IADDR,ISTAT)               !CLEAR SELECTED DEVICE

          CALL  ERRSET(64,,.FALSE.,,.FALSE.,,)   !IGNORE ERROR MESSAGE 64

          CALL BWRITE(IADDR,IADM,4,ISTAT)        !DISPLAY MODE

          AMM=10000.
          LENGTH1=35
          LENGTH2=21
          LENGTH3=80
   1053   FORMAT(F9.5)
          AMN=0.
          WRITE(5,888)
   888    FORMAT('$DO YOU WANT 1)IMPEDANCE  2)ADMITTANCE  ')
          READ(5,889)ILOOP
   889    FORMAT(I2)
          WRITE(5,900)
   900    FORMAT('$','DO YOU WANT 1)LOW, 2)MED.  3)HIGH SPEED  ')
          READ(5,950) IAVE
   950    FORMAT(I2)
```

```
10      WRITE(5,1000)
1000    FORMAT(/'$','ENTER THE VOLTAGE LEVEL (IN VOLTS):       ')
        READ(5,1060,ERR=10) VOLTS
        ENCODE(9,1070,A(3)) VOLTS
        CALL BWRITE(IADDR,A,13,ISTAT)
1060    FORMAT(F10.0)
1070    FORMAT(F9.4)
        NTIMES=1

        WRITE(5,1111)
1111    FORMAT( '$ ENTER # OF POINTS ')
        READ(5,1020)NPTS
1020    FORMAT(I4)
20        NTIMES=NTIMES+1

        IF (ILOOP .EQ.  1)WRITE(5,1010)
1010        FORMAT(/'$','ENTER FREQUENCY(PARALLEL RESONANCE) (IN KHZ):   ')
        IF (ILOOP .EQ.  2)WRITE(5,1011)
1011        FORMAT(/'$','ENTER FREQUENCY(SERIES RESONANCE) (IN KHZ):    ')
        READ(5,1060,ERR=20) START_FREQ
        ITIME=1

        WRITE(5,1030)
1030        FORMAT('$ENTER STEP FREQ (IN KHZ):    ')
        READ(5,1060)STEP_FREQ
        IF(NTIMES .LT.  5)THEN
            GOTO 3000
        ELSE
          TYPE *,'DO YOU WANT TO SWEEP FREQ?'
          READ(5,1035)ISWEEP
1035          FORMAT(A2)
          IF(ISWEEP .EQ.  'N')THEN
            NTIMES=-10
            GO TO 3000
          END IF
        I=1
        ENCODE(8,1066,D(3))STEP_FREQ
        CALL BWRITE(IADDR,D,12,ISTAT)
        WRITE(5,1040)
1040        FORMAT(/,'$ENTER THE STOPPING FREQ (KHZ)  ')
        READ(5,1060)STOP
        ENCODE (9,1070,C(3))STOP
1066        FORMAT(F8.4)
        CALL BWRITE(IADDR,C,13,ISTAT)
        ENCODE(9,1070,E(3))START_FREQ                   !SPOT FREQUENCY
        CALL BWRITE(IADDR,E,13,ISTAT)

        CALL BWRITE(IADDR,IAMM,2,ISTAT)                 !MANUAL MODE
1044        CALL BWRITE(IADDR,IAEX,2,ISTAT)                 !TRIGGER
        DO J=1,80
          ANSWER(J)=0
```

```
          END DO
          CALL BREAD(IADDR,ANSWER,LENGTH3,ISTAT)
          DECODE(12,1050,ANSWER(5))RES(I)
          DECODE(12,1050,ANSWER(21))XES(I)
          DECODE(9,1053,ANSWER(35))FREQ(I)
          IF (FREQ(I) .GE.  STOP)GOTO 88
          CALL BWRITE(IADDR,IADV,2,ISTAT)                  !ADVANCE FREQ.
          I=I+1
          GO TO 1044
          END IF
3000        STEPI=STEP_FREQ

          IF (IAVE.EQ.1) CALL BWRITE(IADDR,IAV1,2,ISTAT)  !AVERAGE SPEED
          IF(IAVE .EQ.  3)CALL BWRITE(IADDR,IAH1,2,ISTAT)    !HIGH SPEED
          IF(IAVE .EQ.  2)CALL BWRITE(IADDR,IAH0,2,ISTAT)   !NORMAL SPEED

          CALL BWRITE(IADDR,IAMM,2,ISTAT)                   !MANUAL MODE
          IF(ILOOP .EQ.  2)CALL BWRITE(IADDR,IAC3,2,ISTAT) !CIRCUIT TYPE 3
          IF(ILOOP .EQ.  1)CALL BWRITE(IADDR,IAC2,2,ISTAT) !CIRCUIT TYPE 2

48          IF(IT .GT.  1)CONTINUE

49          DO I=1,3
            IF(ITIME .GE.  2)THEN
                 IF(I .EQ.  2)GOTO 85
                 FREQUENCY=ABS(FR(I)/(1000.*2*3.14159))
                  ENCODE(9,1070,E(3)) FREQUENCY    ! SPOT STARTING POINT
                  CALL BWRITE(IADDR,E,13,ISTAT)
                   FREQ(I)=FREQUENCY
             ELSE
                  ENCODE(9,1070,E(3)) START_FREQ   ! SPOT STARTING POINT
                  CALL BWRITE(IADDR,E,13,ISTAT)
                 FREQ(I)=START_FREQ
            END IF

            CALL BWRITE(IADDR,IAEX,2,ISTAT)         !TRIGGER THE READING
            DO J=1,80
              ANSWER(J)=0
             END DO
             K=0
            CALL BREAD(IADDR,ANSWER,LENGTH1,ISTAT)
            DECODE(12,1050,ANSWER(5))RES(I)
            DECODE(12,1050,ANSWER(21))XES(I)
1050           FORMAT(E12.2)
            IF(ITIME.EQ.1.AND.I.EQ.1)THEN
               FREQA=FREQ(1)
               XESA=XES(1)
               RESA=RES(1)
            ELSE
            END IF
            FREQ(I)=FREQ(I)*1000
```

```
85          ARRAY(I,1)=RES(I)
          ARRAY(I,2)=XES(I)
          ARRAY(I,3)=1.
          CONS(I)=-(RES(I)*RES(I)+XES(I)*XES(I))
          IF(ITIME.EQ.1)START_FREQ=START_FREQ+STEP_FREQ
        END DO

C        SIMEQ IS A SUBROUTINE THAT SOLVES SIMELTANEOUS EQUATIONS
C          USED TO FIND COEFICIENTS OF A GENERALIZED CIRCLE

        N=3                                        !NUMBER OF PARAMETERS
        CALL SIMEQ(N,ARRAY,CONS,DEF)
        IF(N .EQ.  0)GO TO 20
        CENTERX=-DEF(1)/2.                              !X VALUE OF CENTER
        CENTERY=-DEF(2)/2.                              !Y VALUE OF CENTER
        RADIUS=.5*SQRT(DEF(1)*DEF(1)+DEF(2)*DEF(2)-4*DEF(3))
        IF(ILOOP .EQ.  2)RESIS=1./(2*RADIUS)     !RESISTANCE (ADMITTANCE)
        IF(ILOOP .EQ.  1)RESIS=2*RADIUS          !RESISTANCE (IMPEDANCE)

C        SLOPE IS THE TAN(THETA) IN EQUATION 1

        SLOPE1=((XES(1)-CENTERY)/(RES(1)-CENTERX+RADIUS))
        SLOPE2=((XES(2)-CENTERY)/(RES(2)-CENTERX+RADIUS))
        SLOPE3=((XES(3)-CENTERY)/(RES(3)-CENTERX+RADIUS))

        COEFF(1,1)=SLOPE1*RESIS*6.283185*FREQ(1)
        COEFF(2,1)=SLOPE2*RESIS*6.283185*FREQ(2)
        COEFF(1,2)=1.
        COEFF(2,2)=1.
        COLUMN(1)=(2*3.14159*FREQ(1))**2
        COLUMN(2)=(2*3.14159*FREQ(2))**2

        N=2
        CALL SIMEQ(N,COEFF,COLUMN,ANS)
        IF(N .EQ.  0)GOTO 20

C        ANS(1) is the Inductor
C        ANS(2) is the Resonant Freq.
        IF(ANS(2) .LT.  0)GOTO 20

        ANS(1)=1/ANS(1)
        ANS(2)=SQRT(ANS(2))
        IF(ANS(2) .EQ.  0)GOTO 20
        RESONANCE=ANS(2)/6283.185
        WRITE(5,77)ANS(2)/6283.185
77        FORMAT(' FREQ= ',F10.3)

        IF(ABS(ANS(2)-OMEGA)/6283.LE.(.0005*FREQA) .OR.  ITIME .GE.  25)THEN
            ANS(2)=(OMEGA+ANS(2))/2.
          ANS(1)=(RINDUCTOR+ANS(1))/2.
          GOTO 50
```

```
      ELSE
        OMEGA=ANS(2)
        RINDUCTOR=ANS(1)
      END IF

C      ANGLES OF OTHER 2 POINTS

      TRANSX1=RES(2)-CENTERX
      TRANSY1=XES(2)-CENTERY
      TRANSA1=ATAN2(TRANSY1,TRANSX1)
      X2=COS(TRANSA1+2.094395)*RADIUS+CENTERX
      X3=COS(TRANSA1-2.094395)*RADIUS+CENTERX
      Y2=SIN(TRANSA1+2.094395)*RADIUS+CENTERY
      Y3=SIN(TRANSA1-2.094395)*RADIUS+CENTERY

      SLOPE1=(Y2-CENTERY)/(X2-CENTERX+RADIUS)
      SLOPE3=(Y3-CENTERY)/(X3-CENTERX+RADIUS)
      B1=-SLOPE1*RESIS
      B2=-SLOPE2*RESIS
      B3=-SLOPE3*RESIS

      FR(1)=-B1-SQRT(B1*B1+4.*ANS(1)**2*(ANS(2)*ANS(2)))
      FR(1)=FR(1)/(2*ANS(1))
      FR(2)=FREQ(2)*2*3.14159
      FR(3)=-B3-SQRT(B3*B3+4.*ANS(1)**2*(ANS(2)*ANS(2)))
      FR(3)=FR(3)/(2*ANS(1))
      ITIME=ITIME+1
      IF(ITIME .GE. 2)GOTO 49
50      R=SQRT(RESA*RESA+XESA*XESA)
      THETA=ATAN2(XESA,RESA)
      A0=SQRT((CENTERX-RESA)**2 + (CENTERY-XESA)**2)
      CONVERT=1.74532E-02
      TIM=359./NPTS
      PI=3.14159
      TRANSX=RESA-CENTERX
      TRANSY=XESA-CENTERY
      THETA=ATAN2(TRANSY,TRANSX)
      I=1
      DO IT=1,NPTS
      DELTA2=IT*TIM*CONVERT+THETA
      X3=(COS(DELTA2)*RADIUS)+CENTERX
      Y3=(SIN(DELTA2)*RADIUS)+CENTERY
        SLOPE3=(Y3-CENTERY)/(X3-CENTERX+RADIUS)

        B3=-SLOPE3*RESIS

        FRE(I)=-B3+SQRT(B3*B3+4.*ANS(1)**2*(ANS(2)*ANS(2)))
        FRE(I)=FRE(I)/(2.*ANS(1))
        FREQUENCY=ABS(FRE(I)/(1000.*2*3.14159))
9         TOLERANCE1=2.5*RESONANCE
        IF ( FREQUENCY .GT. TOLERANCE1)GOTO 70
```

```
                ENCODE(9,1070,E(3)) FREQUENCY    ! SPOT STARTING POINT
          CALL BWRITE(IADDR,E,13,ISTAT)
          CALL BWRITE(IADDR,IAEX,2,ISTAT)        !TRIGGER THE READING
         DO J=1,80
             ANSWER(J)=0
          END DO
          K=0
         CALL BREAD(IADDR,ANSWER,LENGTH1,ISTAT)
         DECODE(12,1050,ANSWER(5))RES(I)
         DECODE(12,1050,ANSWER(21))XES(I)
         IF(RES(I) .GT.  1.3E6 .OR.  XES(IT) .GT.  1.3E6)GO TO 70
         FREQ(I)=FREQUENCY
          MAG(I)=SQRT(RES(I)*RES(I)+XES(I)*XES(I))
         I=I+1
 70      END DO
 88      CALL RSORT(RES,FREQ,XES,I-1,1)
       GS=RES(1)
       BS=XES(1)
       FS=FREQ(1)
       TAN0=ATAN2(BS,GS)
       CALL RSORT(FREQ,RES,XES,I-1,1)
       FLAG=0
       IT=2
       XESMAX=-1E12
       RESMAX=-1E12
       XESMIN=1E12
       RESMIN=1E12
       ADMMIN=1E12
       ADMMAX=0
       TANMIN=1E12
       DO J=2,I-1
         IF(XES(J) .GT.  BS .AND.  FLAG .EQ.0 .AND.  XES(J) .GT.  0)THEN
            FREQ(1)=FREQ(J)
            RES(1)=RES(J)
            XES(1)=XES(J)
            GO TO 500
         ELSE
            FREQ(IT)=FREQ(J)
            RES(IT)=RES(J)
            XES(IT)=XES(J)
            TAN1=ATAN2(XES(IT),RES(IT))
            FLAG=1
             ADM(IT)=SQRT(RES(IT)**2 +XES(IT)**2)
            IF(FREQ(IT) .LE.  FS .AND.  IT .GT.  1)THEN
              IF(XES(IT) .GE.  XESMAX)THEN
                 XESMAX=XES(IT)
                FH=FREQ(IT)
                GH=RES(IT)
                BH=XES(IT)
              END IF
              IF(ADM(IT) .GT.  ADMMAX .AND.  ILOOP .EQ.  2)THEN
```

```
                    ADMMAX=ADM(IT)
                    FM=FREQ(IT)
                    GM=RES(IT)
                    BM=XES(IT)
                  END IF
                  IF(XES(IT-1) .LT.  0 .AND.  XES(IT) .GT.  0)THEN
                    FRES=FREQ(IT)
                    GR=RES(IT)
                    BR=XES(IT)
                  END IF
                END IF
                IF(FREQ(IT) .GE.  FS .AND.  IT .GT.  1)THEN
                  IF(XES(IT) .LE.  XESMIN)THEN
                    XESMIN=XES(IT)
                    FL=FREQ(IT)
                    GL=RES(IT)
                    BL=XES(IT)
                  END IF
                   IF(XES(IT-1) .LT.  0 .AND.  XES(IT) .GT.  0)THEN
                    FRES=FREQ(IT)
                    GR=RES(IT)
                    BR=XES(IT)
                  END IF
                   IF(ADM(IT) .GT.  ADMMAX .AND.  ILOOP .EQ.  1)THEN
                     ADMMAX=ADM(IT)
                     FN=FREQ(IT)
                           GN=RES(IT)
                    BN=XES(IT)
                   ENDIF
                END IF
              IT=IT+1
              END IF
 500           END DO
            IF(ILOOP.EQ.1)THEN
            WRITE(5,1109)
 1109           FORMAT(///,9X,'TYPE',11X,'FREQUENCY(KHZ)',2X,'RESISTANCE',2X,
            1'REACTANCE')
            ELSE
            WRITE(5,1110)
 1110           FORMAT(///,9X,'TYPE',11X,'FREQUENCY(KHZ)',2X,'CONDUCTANCE',2X,
            1'SUSCEPTANCE')
            END IF
            WRITE(5,1112)
 1112           FORMAT(9X,'----',11X,'--------------',2X,'------------',
            12X,'-----------',/)
            IF(FRES .EQ.  0)THEN
              IF(BL .LT.  0)THEN
                 FRES=FS
                 GR=GS
                 BR=BS
                 WRITE(5,1130)FRES,GR,BR
```

```
           ELSE
            WRITE(5,1120)
1120            FORMAT(1X,'RESONANCE',17X,' DOES NOT EXIST')
           END IF
         ELSE
           IF(ILOOP .EQ.  2)WRITE(5,1130)FRES,GR,BR
1130            FORMAT(1X,'RESONANCE',16X,F8.3,7X,E8.3,5X,E9.3)
           IF(ILOOP .EQ.  1)WRITE(5,1131)FRES,GR,BR
1131            FORMAT(1X,'ANTIRESONANCE',12X,F8.3,7X,E8.3,5X,E9.3)
         END IF
         CALL BWRITE(IADDR,IAMM,2,ISTAT)                       !MANUAL MODE
         FLAG1=0
         ENCODE(8,1066,D(3)).1                                   !STEP SIZE
         CALL BWRITE(IADDR,D,12,ISTAT)
         IF(ILOOP .EQ.  1)CALL BWRITE(IADDR,IAC3,2,ISTAT)
         IF(ILOOP .EQ.  2)CALL BWRITE(IADDR,IAC2,2,ISTAT)
         IF(ILOOP .EQ.  2)ENCODE(9,1070,E(3))FL
         IF(ILOOP .EQ.  1)ENCODE(9,1070,E(3))FH
         CALL BWRITE(IADDR,E,13,ISTAT)                              !SPOT
         GP=0
1270       CALL BWRITE(IADDR,IAEX,2,ISTAT)
         DO J=1,80
           ANSWER(J)=0
         END DO
         CALL BREAD(IADDR,ANSWER,LENGTH3,ISTAT)
         DECODE(12,1050,ANSWER(5))A1
         DECODE(12,1050,ANSWER(21))B1
         DECODE(9,1053,ANSWER(35))F1
         IF(A1 .GE.  GP )THEN
           FP=F1
           GP=A1
           BP=B1
            IF(ILOOP .EQ.  2)CALL BWRITE(IADDR,IADV,2,ISTAT)     !ADVANCE
            IF(ILOOP .EQ.  1)CALL BWRITE(IADDR,IREV,2,ISTAT)     !REVERSE
           GO TO 1270
         ELSE
           FLAG1=FLAG1+1
           IF(FLAG1 .EQ.  1) THEN
              IF(ILOOP.EQ.2)CALL BWRITE(IADDR,IADV,2,ISTAT)
              IF(ILOOP.EQ.1)CALL BWRITE(IADDR,IREV,2,ISTAT)
              FP=F1
             GP=A1
             BP=B1
             GOTO 1270
           END IF
         END IF
         NUM=8
         CRX(1)=GS
         CRY(1)=BS
         CRX(2)=GP
         CRY(2)=BP
```

```
         CRX(3)=GM
         CRY(3)=BM
         CRX(4)=GN
         CRY(4)=BN
         CRX(5)=GH
         CRY(5)=BH
         CRX(6)=GL
         CRY(6)=BL
         IF(FRES .EQ.  0)THEN
           NUM=NUM-1
         ELSE
           CRX(7)=GR
           CRY(7)=BR
         END IF
         IF(FA .EQ.  0)THEN
           NUM=NUM-1
         ELSE
           CRX(8)=GA
           CRY(8)=BA
         END IF
           IF(ILOOP .EQ.  2)WRITE(5,1160)FS,GS,BS
           IF(ILOOP .EQ.  1)WRITE(5,1160)FP,GP,BP
1160            FORMAT(1X,'SERIES RESONANCE',9X,F8.3,7X,E8.3,5X,E9.3)
           IF(ILOOP .EQ.  2)WRITE(5,1170)FP,GP,BP
           IF(ILOOP .EQ.  1)WRITE(5,1170)FS,GS,BS
1170            FORMAT(1X,'PARALLEL RESONANCE',7X,F8.3,7X,E8.3,5X,E9.3)
           IF(ILOOP .EQ.  2)WRITE(5,1180)FM,GM,BM
1180            FORMAT(1X,'MAXIMUM ADMITTANCE',7X,F8.3,7X,E8.3,5X,E9.3)
            IF(ILOOP .EQ.  1) WRITE(5,1280)FN,GN,BN
1280            FORMAT(1X,'MAXIMUM IMPEDANCE',8X,F8.3,7X,E8.3,5X,E9.3)
            WRITE(5,1190)FH,GH,BH
1190            FORMAT(1X,'HIGH POINT',15X,F8.3,7X,E8.3,5X,E9.3)
           WRITE(5,1200)FL,GL,BL
1200            FORMAT(1X,'LOW POINT',16X,F8.3,7X,E8.3,5X,E9.3)
         WRITE(5,1300)7
1300          FORMAT(//,' ',A1)
          IF(ILOOP .EQ.  2)TYPE *,'ADMITTANCE LOOP'
         IF(ILOOP .EQ.  1)TYPE *,'IMPEDANCE LOOP'
         CALL FILE(IT-1,RES,XES)
         TYPE *,' '
         TYPE *,'CRITICAL FREQUENCIES'
         CALL FILE(NUM,CRX,CRY)
         TYPE *,' '
         TYPE *,'FREQ VS.  MAG.'
         CALL FILE(IT-1,FREQ,MAG)
         CALL BDEVCL(IADDR,ISTAT)                     !CLEAR SELECTED
         END
```

APPENDIX C

Running MICAM

```
 RUN SUPER
DO YOU WANT 1) IMPEDANCE  2) ADMITTANCE  1
DO YOU WANT 1) LOW,  2) MED,  3) HIGH SPEED  3

ENTER THE VOLTAGE LEVEL (IN VOLTS):   .1
 ENTER # OF POINTS  100

ENTER FREQUENCY (PARALLEL RESONANCE) (IN KHZ):   15
ENTER STEP FREQ (IN KHZ):   .5
FREQ=    15.304
FREQ=    15.293
FREQ=    15.291
```

TYPE	FREQUENCY(KHZ)	RESISTANCE	REACTANCE
ANTIRESONANCE	15.291	.107E+07	0.100E+05
SERIES RESONANCE	14.384	.485E-02	-.288E-02
PARALLEL RESONANCE	15.291	.107E+07	0.100E+05
MAXIMUM IMPEDANCE	15.291	.107E+07	0.100E+05
HIGH POINT	15.284	.530E+06	0.530E+06
LOW POINT	15.297	.630E+06	-.540E+06

```
IMPEDANCE LOOP
FILE NAME FOR X,Y DATA:   DATA1

CRITICAL FREQUENCIES
FILE NAME FOR X,Y DATA:   DATA2

FREQ VS.  MAG.
FILE NAME FOR X,Y DATA:   DATA3
$
```

```
 RUN SUPER
DO YOU WANT  1) IMPEDANCE  2) ADMITTANCE  2
DO YOU WANT  1) LOW,  2) MED,  3) HIGH SPEED  3

ENTER THE VOLTAGE LEVEL (IN VOLTS):   .1
 ENTER # OF POINTS  100

ENTER FREQUENCY(SERIES RESONANCE) (IN KZH):   14
ENTER STEP FREQ (IN KHZ):   .5
FREQ=    14.390
FREQ=    14.372
FREQ=    14.372
```

TYPE	FREQUENCY(KHZ)	CONDUCTANCE	SUSCEPTANCE
RESONANCE	14.375	.678E-02	0.300E-04
SERIES RESONANCE	14.373	.679E-02	0.540E-03
PARALLEL RESONANCE	15.291	.107E+07	0.000E+00
MAXIMUM ADMITTANCE	14.373	.677E-02	0.790E-03
HIGH POINT	14.357	.311E-02	0.379E-02
LOW POINT	14.391	.327E-02	-.316E-02

```
ADMITTANCE LOOP
FILE NAME FOR X,Y DATA:    DATA1

CRITICAL FREQUENCIES
FILE NAME FOR X,Y DATA:    DATA2

FREQ VS.  MAG.
FILE NAME FOR X,Y DATA:    DATA3
$
```